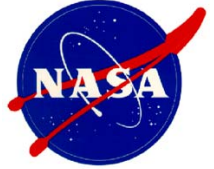


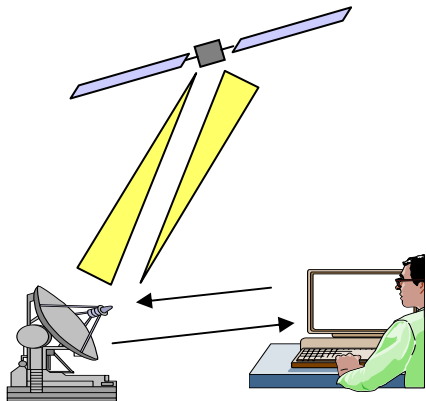
An Integrated Approach to Earth Science Observation Scheduling

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Frank, Lina Khatib, David Smith
NASA Ames Research Center

Introduction

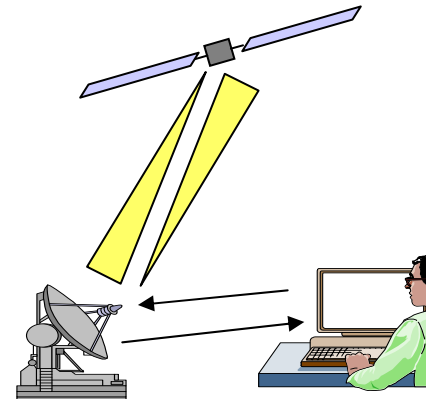


- The Committee on Earth Observation Satellites estimates that international space agencies are planning more than 80 earth observing missions over the next 15 years, involving over 200 different instruments, providing measurements of many environmental change parameters.
- Large volumes of image data will be acquired.
- Multiple heterogeneous instruments allow for the possibility of coordination to accomplish goals.
- This work describes how automated scheduling technology can be applied to improving the management of science campaigns
 - Increasing the scientific value of the data obtained
 - Allow for coordination for accomplishing science goals



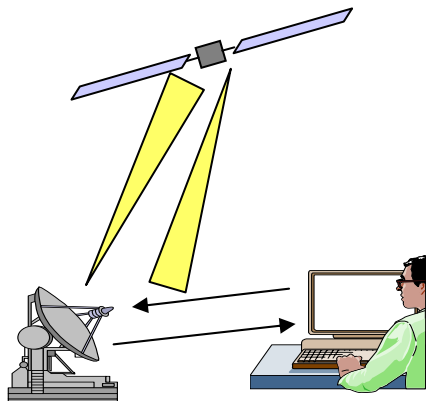
Performed on the ground for periods covering a day or more

Command sequences uplinked and executed rigorously

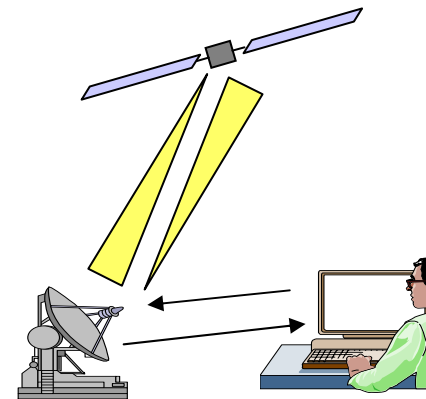


Scientific utility of scenes determined on the ground

Little coordination among missions



Improvements through better coordination and a more flexible execution policy.

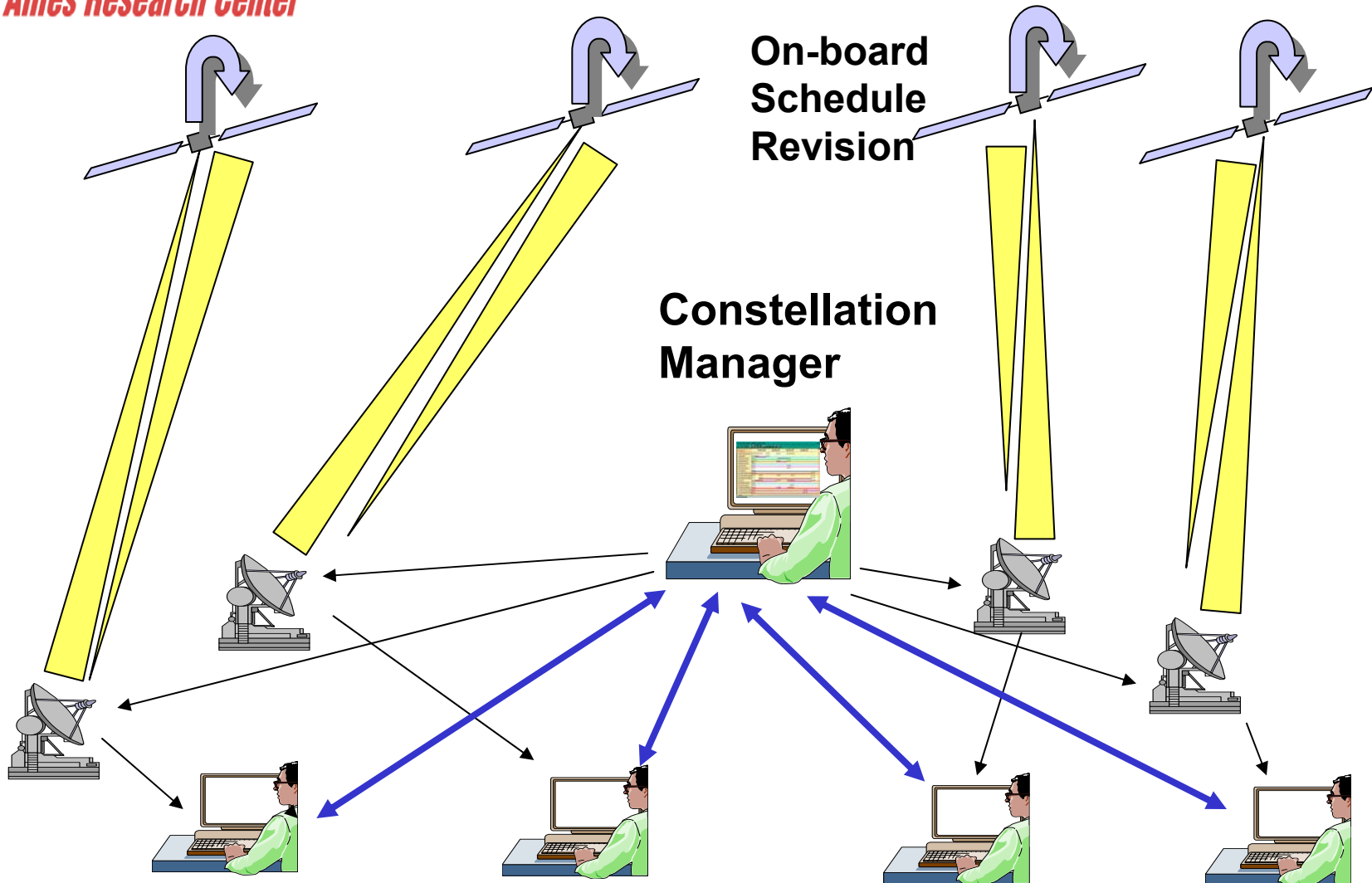


Combined Science

“One of the outstanding science questions that have emerged... is: what is the role of clouds and aerosols in heating and cooling of the global Climate? The afternoon constellation will make a superb series of measurements that will directly answer this question. For example, the radiation budget measurements by CERES can be used to address the role of subvisible cirrus in the radiation budget. Identification regions of subvisible cirrus can be made by the MODIS IR measurement, but the key parameter, the height of the cirrus cloud and optical thickness will be made by CALIPSO's lidar.”

M. Schoeberl, *The Afternoon Constellation: A Formation of Earth Observing Systems for the Atmosphere and Hydrosphere*

Coordinated Scheduling



Why On-board Schedule Revision?



- Relative utility of observation can change dynamically
 - Unexpected cloud cover
 - Serendipitous events
 - Changes in resource capabilities
 - Loss of ground station
 - On-board storage
- Satellites can only communicate with ground occasionally
 - Thus, it may be infeasible to generate desired schedule changes on the ground and uplink them.
- Thus, to maximize utility of acquired images, do some of the decision-making on-board.

Observation Scheduling for Earth orbiting satellites



- Given a set of requests for images of the Earth, a set of sensing instruments, and a set of constraints, produce a set of assignments of instruments and viewing times to those requests that satisfy the constraints.
- Constraints associated with EOS Scheduling
 - On-board storage (Solid State Recorder) capacity
 - Instrument duty cycle
 - Slewing (for agile instruments)
- Requests associated with scientific utility
 - Importance in meeting science goals
 - Expected utility given viewing conditions (cloud cover)
- Instruments are oversubscribed; more requests than can be serviced.
- Objective: maximize the sum of the utility of requests put on schedule



Central Scheduler Search



- *Greedy search* requires a heuristic that orders the decisions made by the scheduler in the process of building a complete, consistent schedule.
- Heuristic informs the scheduler as to what observation request should be added next to the schedule, and when the observation should be taken.
- A common heuristic for ordering requests is in terms of priority, with higher priority requests added to the schedule first.
 - Forms the basis for many of the previous heuristics used in observation scheduling, for example, Spot scheduling, Landsat 7 scheduling.
 - We have been experimenting with other heuristics based on contention for time and SSR (not discussed in paper).

Greedy Sampling



Generalization of greedy search technique by adding an element of randomness to the selection process.

Instead of always making decisions based on the heuristic advice, bias each decision based on the heuristic rankings of the possible choices, thus allowing for the possibility of decisions that do not follow heuristic advice.

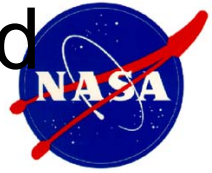
Utilization of the bias allows the scheduler to potentially compensate for limitations in the general usefulness of the heuristic, and to allow for sampling of the solution space.

The belief is that this way of achieving a balance between exploration and exploitation of heuristic advice will yield improved schedules.

This approach, called Heuristic Biased Stochastic Sampling, was used to select observations and times for the central scheduler.



On board processing: assumptions and implications



- Limited time for making on-board decisions
- Limited processing power
- Limited inputs

Existing schedule

Set of additional (desirable) observations

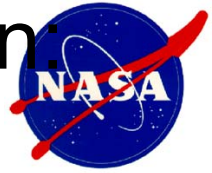
No knowledge of other satellites

- Updates on observation priority/utility

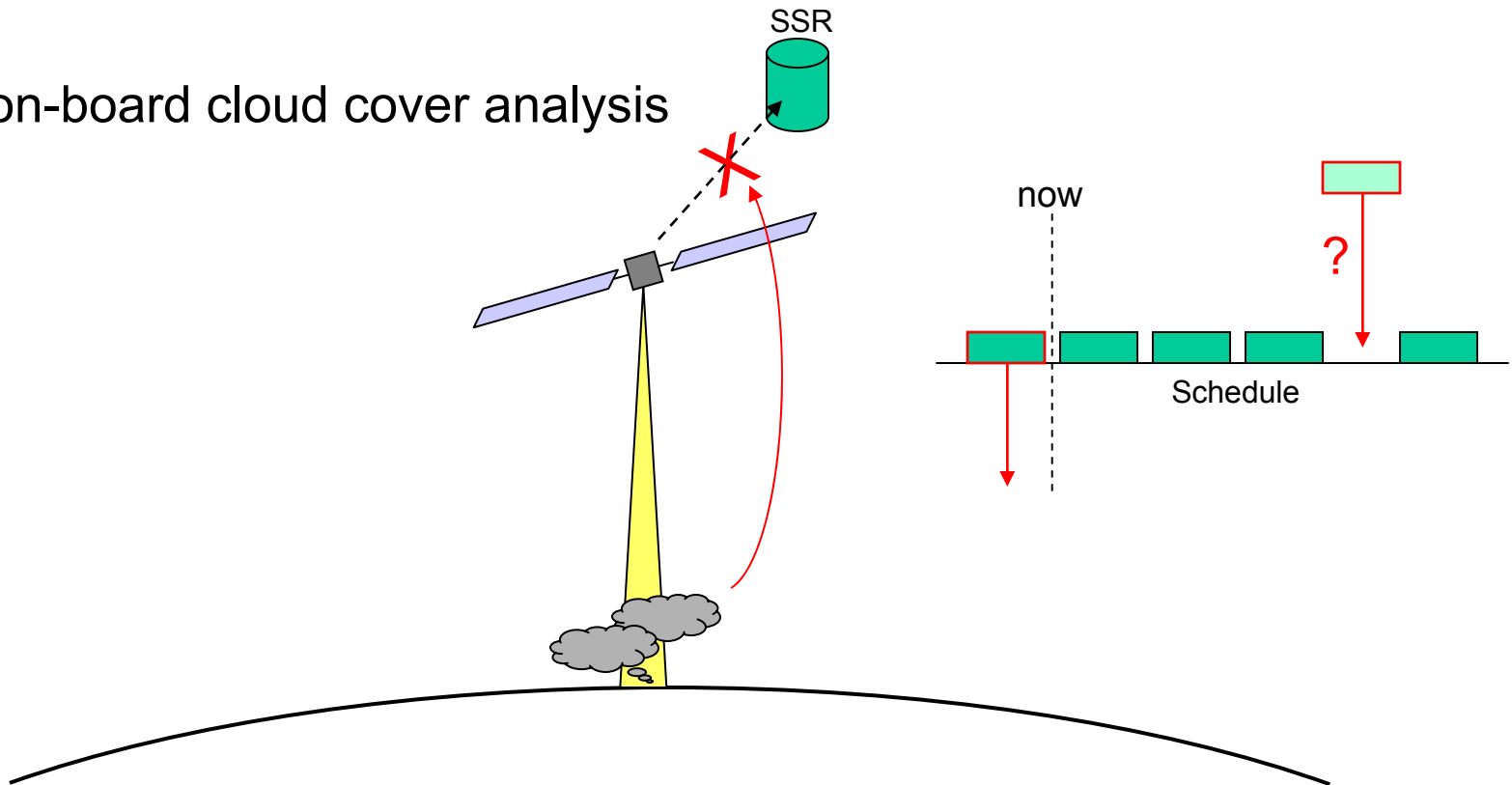
→ *Schedule Revision*, Not rescheduling

→ System reverts to executing nominal schedule produced by central scheduler, unless changes in utility are observed.

Scenario for on-board schedule revision: discard acquired image

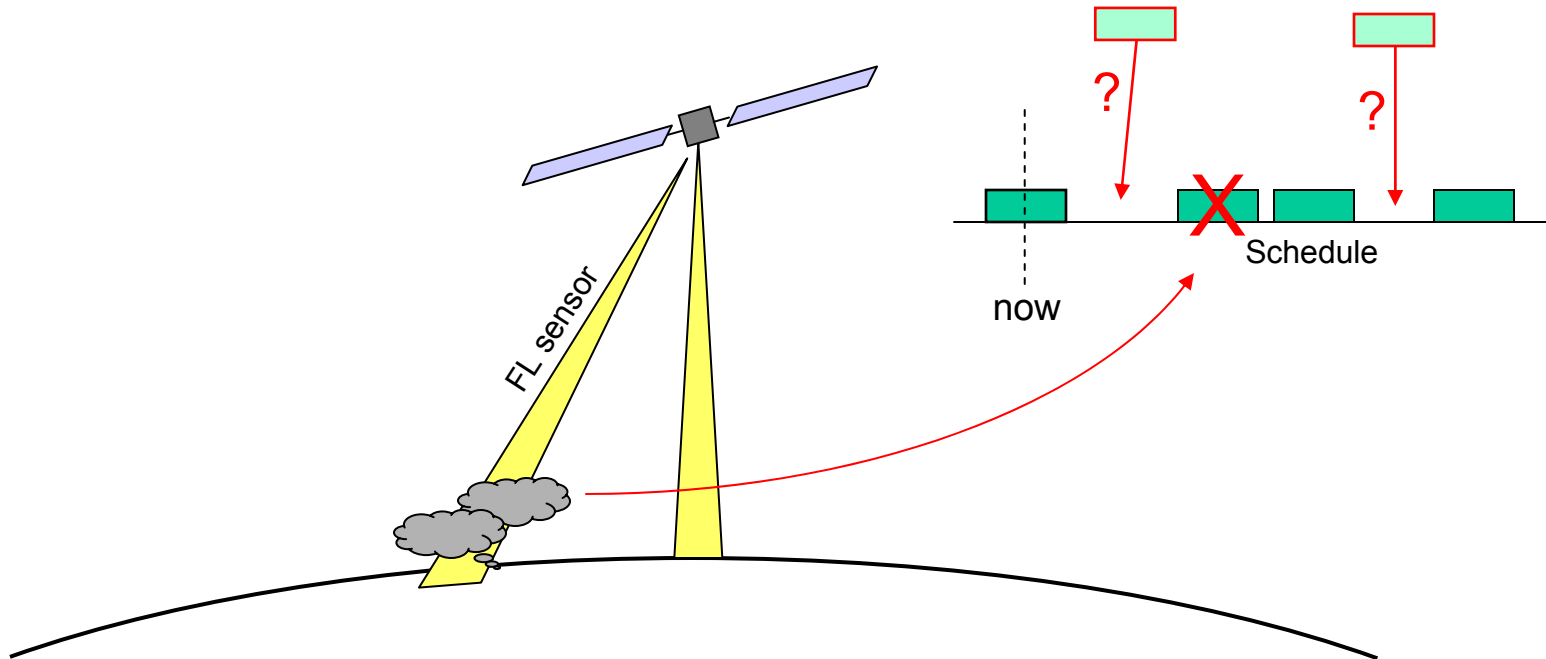


Requires on-board cloud cover analysis



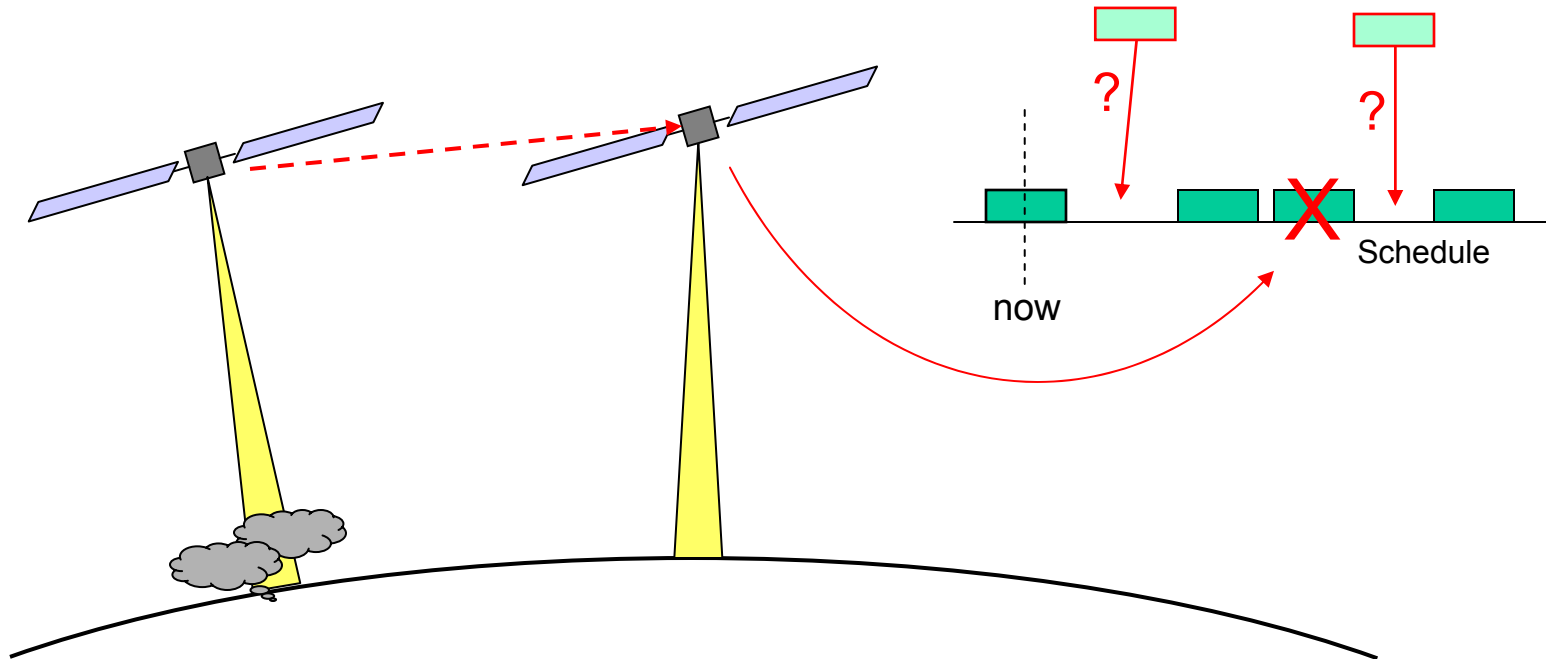
Revise Future Observations

Requires forward looking sensors



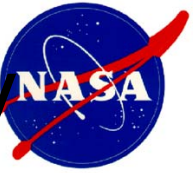
Revise Future Observations

Requires inter-satellite communication



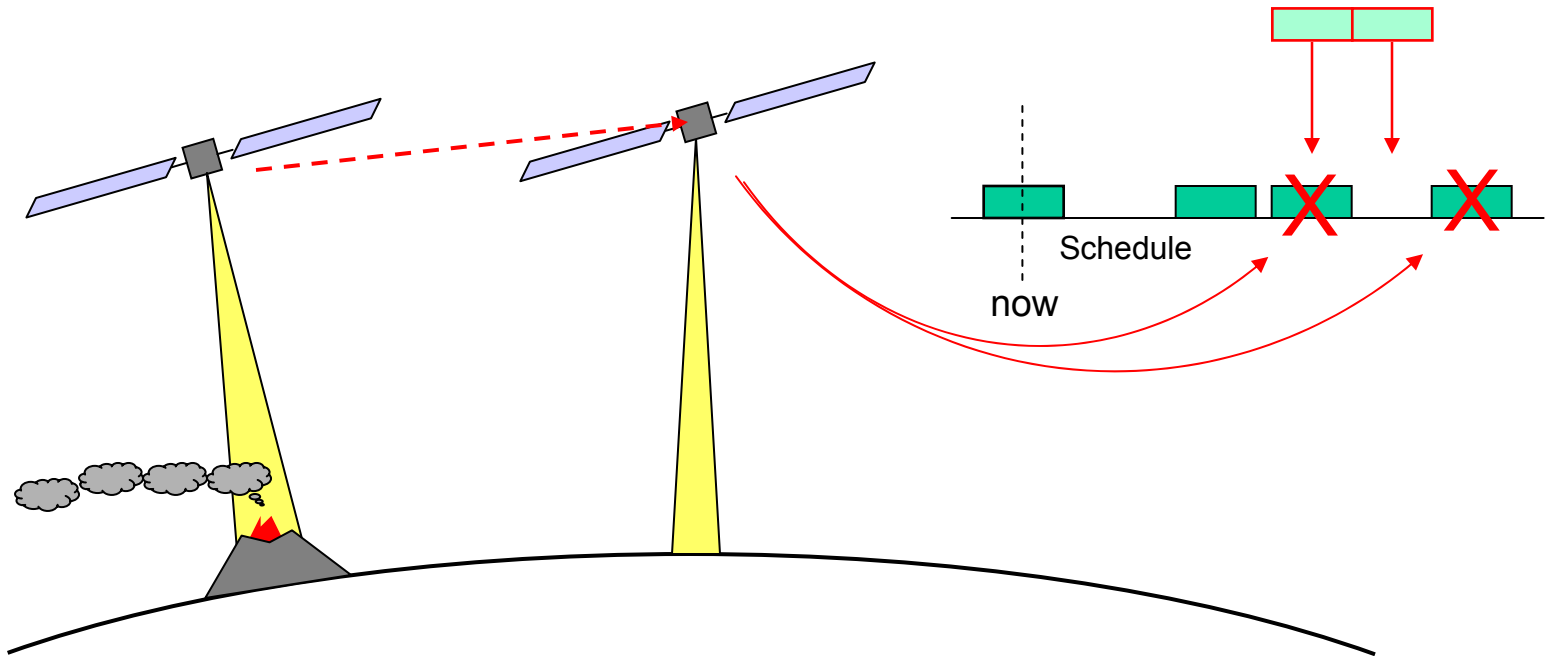


Respond to Targets of Opportunity



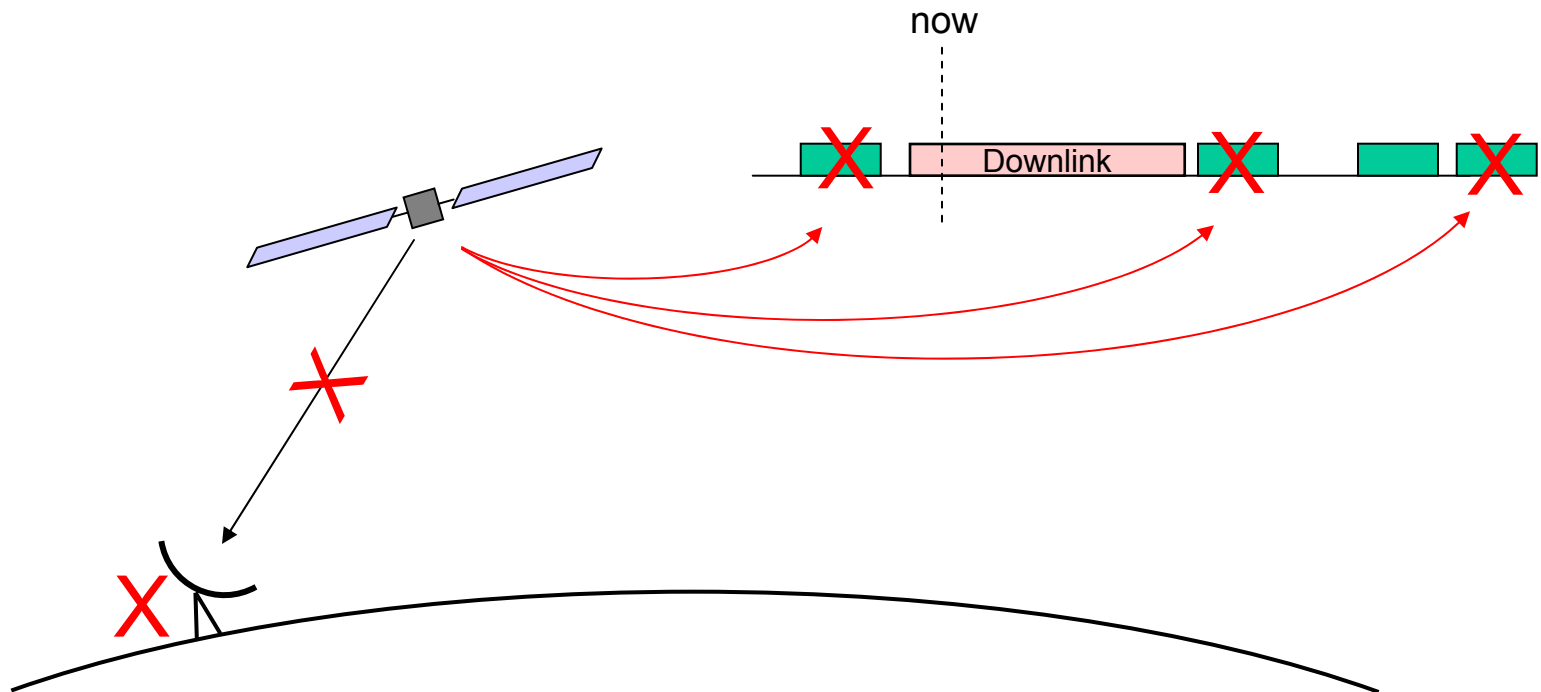
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Discard future observations
Insert new obs.



Ground Station Loss

Discard data
& future observations





Schedule Revision System: Approach



Maintain a surplus of observations, and incrementally discard those of lesser value, as necessary, in order to retain those of higher value.

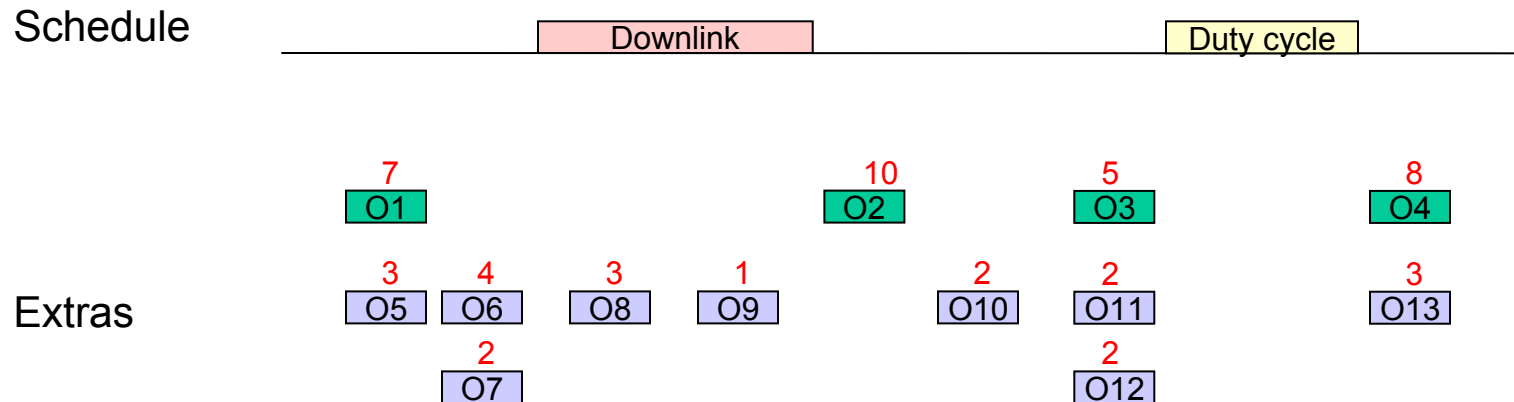
Over-commitment helps ensure that a full complement of useful observations will be collected

Interleave taking images and evaluating acquired or future opportunities

Use greedy heuristic lookahead search for finding candidates with high utility.

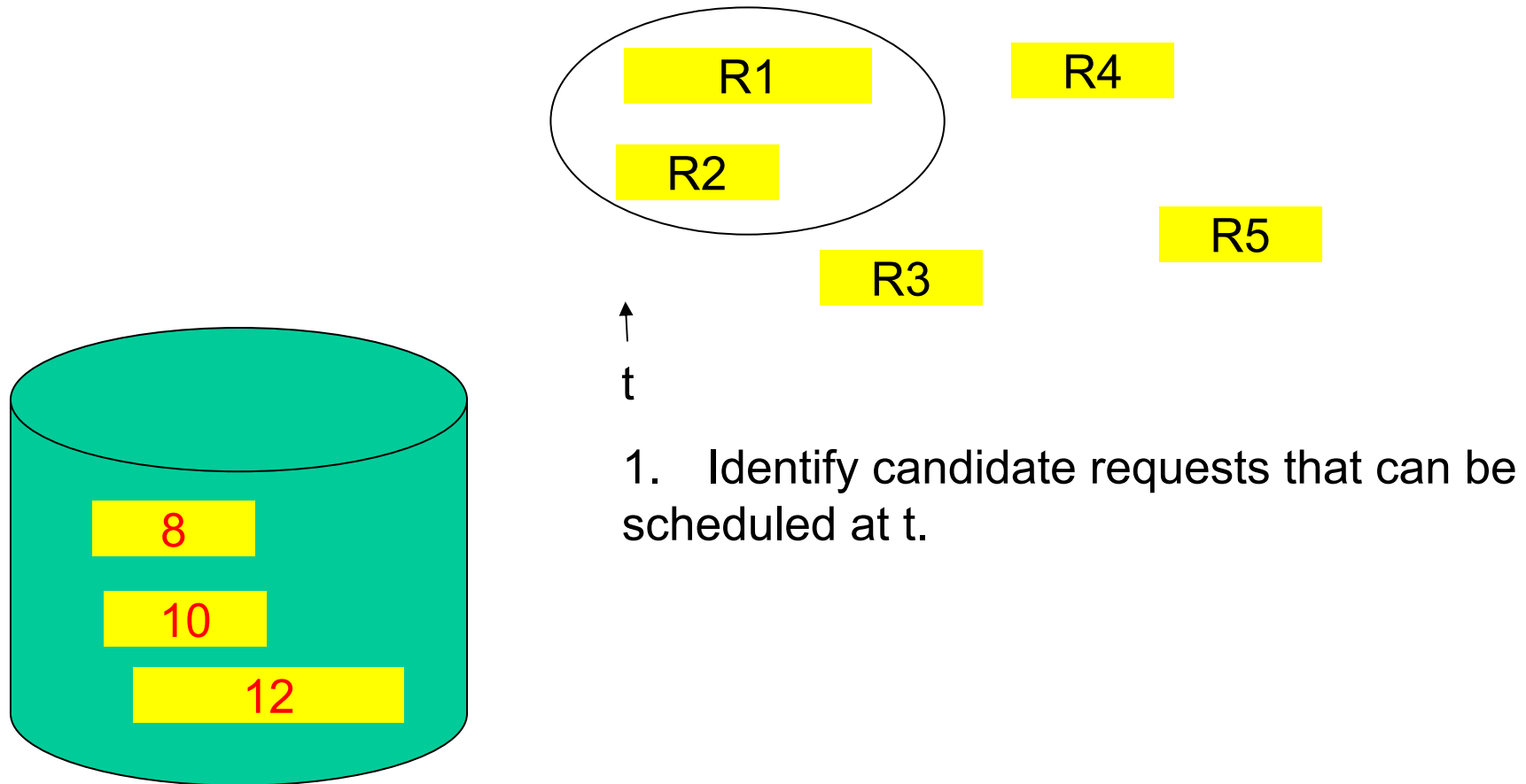
Set-up

1. Elevate utility of scheduled observations.
2. Remove scheduled observations.

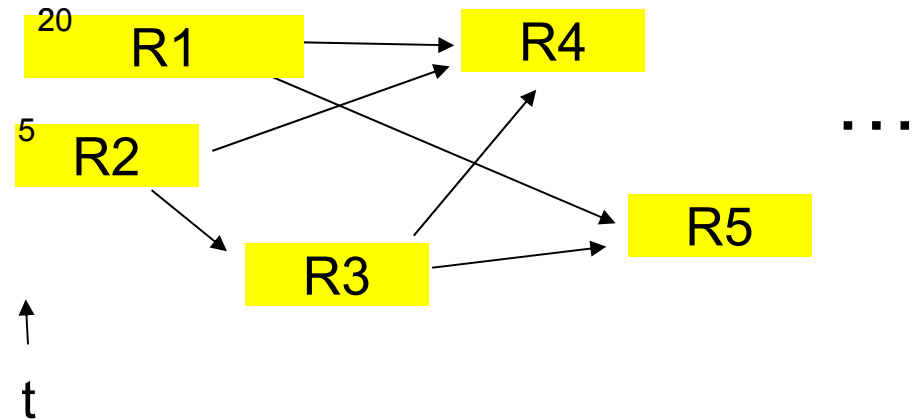
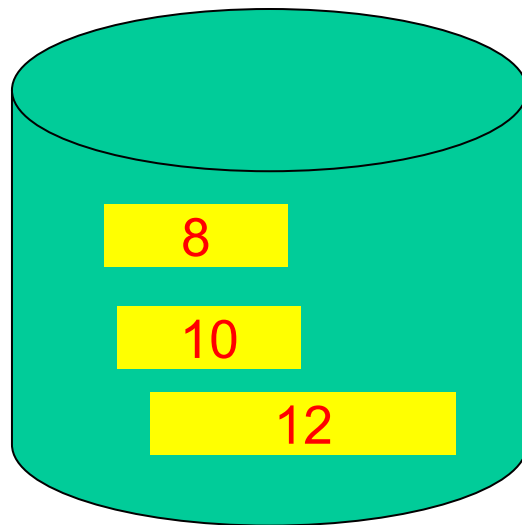


Allows system to revert to original schedule unless there is a change in utility.

Interleaved Execution and Revision

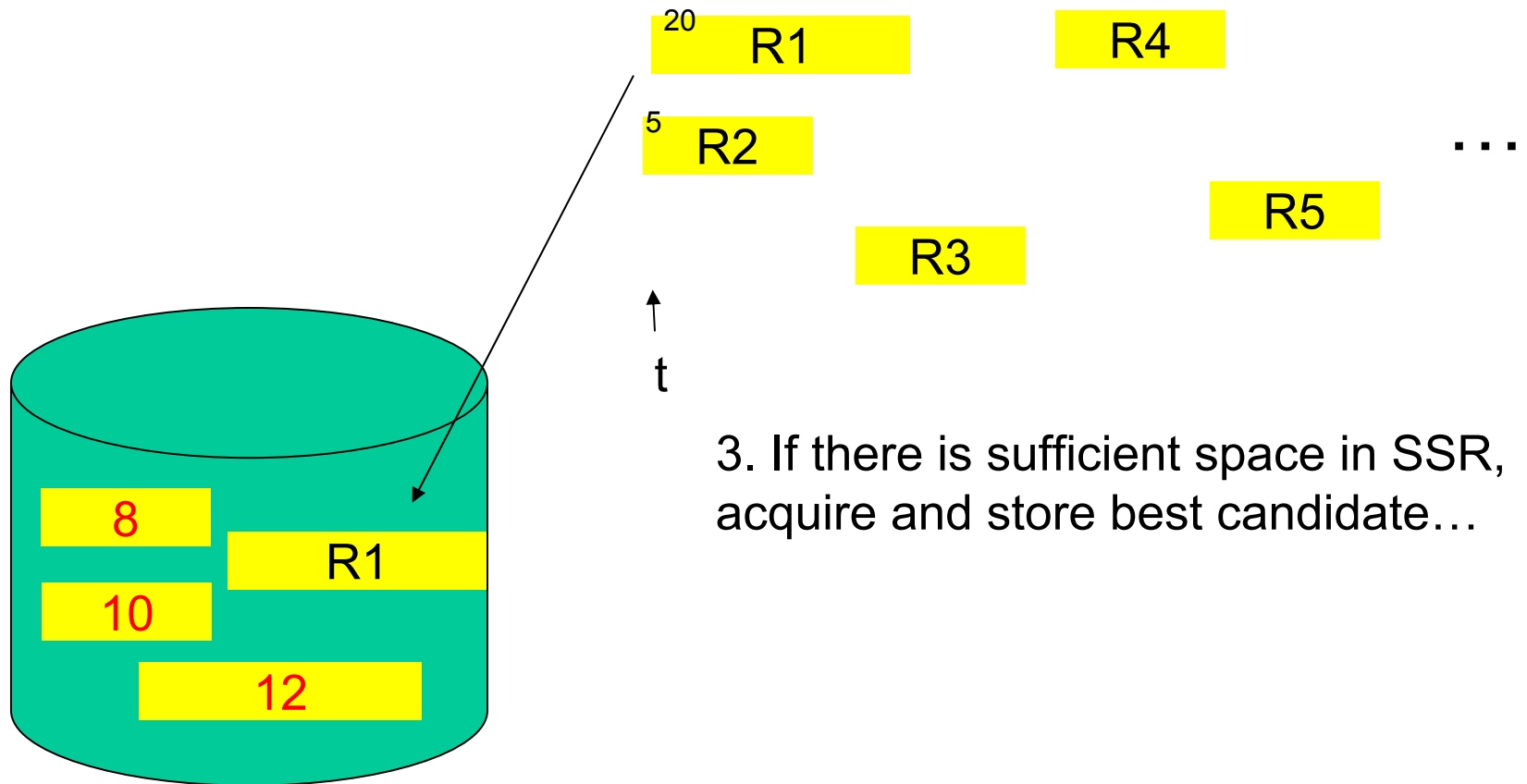


Interleaved Execution and Revision

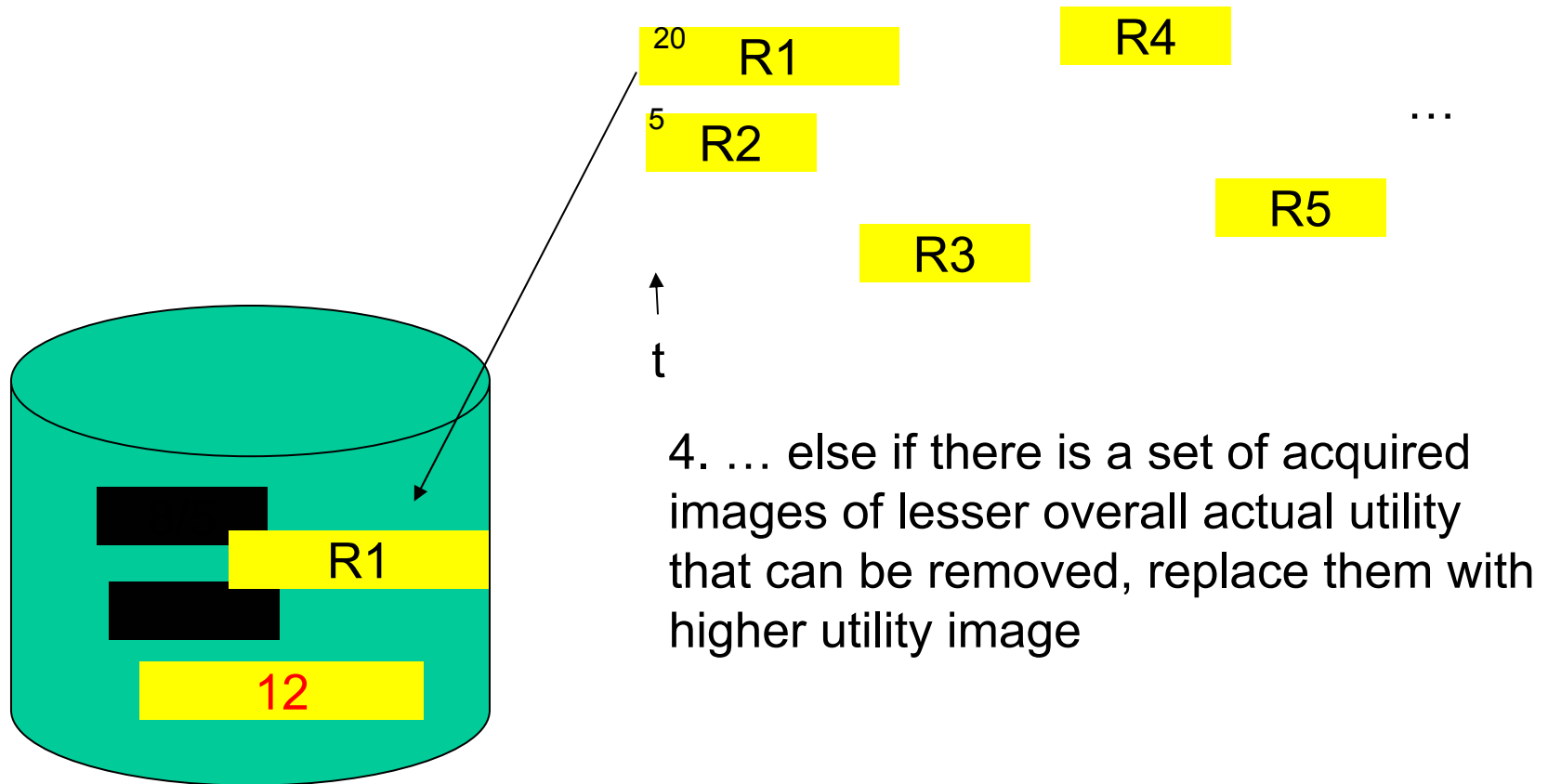


2. Compute heuristic value of each candidate request

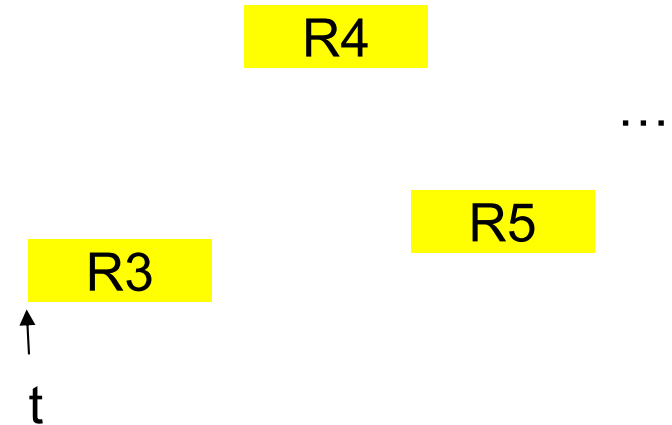
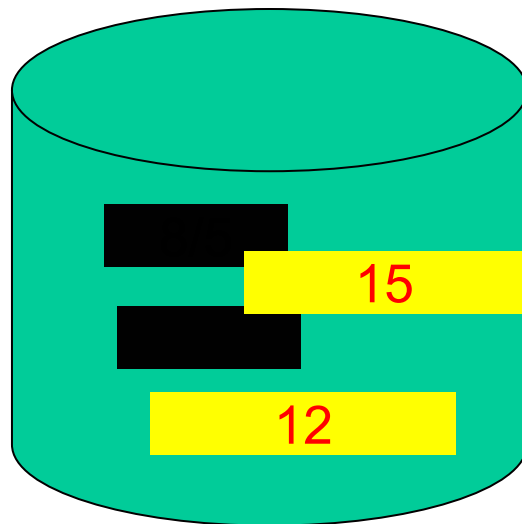
Interleaved Execution and Revision



Interleaved Execution and Revision

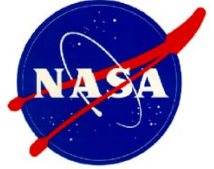


Interleaved Execution and Revision



5. Access actual utility of acquired image and repeat process.

Experiments



- Goal: study expected gain in overall science utility as a result of performing on-board schedule revision over rigorous execution of schedule produced on the ground.
 - Frequency and types of utility revisions
 - SSR capacity
 - Ground schedule bias
 - Number of alternative observations considered
 - Lookahead strategy
 - Single/multiple instruments
- Two scenarios
 - On-board image analysis software for acquired images
 - Forecast information for future observations
- Problem instance descriptions
 - 9 hour scheduling horizons and up to 300 requests

Summary of Results

- Revision works better than no revision
 - Up to 14 % improvement with variable lookahead
- With refinements to lookahead strategies, solutions can be achieved at a reasonable time.
 - To evaluate candidate r , must examine all trees of partial schedules rooted at r .
 - Can introduce pruning techniques to cut down on size of search.



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Summary and Future Work



- Approach to managing EOS science planning based on combined constellation scheduling + on-board schedule revision.
 - Central Scheduler manages fleets of satellites requires detailed knowledge of resources.
 - On-board system revises schedules produced by central schedule based on changes in actual or expected utility of observations.
- Motivation is
 - Increasing demand for high quality science data
 - Expected increase in volume of data
 - Anticipated need for coordinated science
- Future work will address issues related to the interactions between constellation scheduling and individual mission scheduling.